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TO OPTICAL TRANSFORMATIONS

by

Zheng Shanfeng, Wang Tianji

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APPLICATION OF COMPUTER-GENERATED HOLOGRAMS TO OPTICAL TRANSFORMATIONS

Zheng Shanfeng and Wang Tianji; Both of Guangzhou Institute of Electronics Technology, Chinese Academy of Sciences, Guangzhou 510075

Abstract

Ring-to-line, line-to-point and ring-to-point optical transformations by using computer generated holograms as a holographic lens are discussed in this paper. A liquid crystal television spatial light modulator fabricates computer generated holograms in quasi-real time.

Key words: **CGH, optical transformation, liquid crystal television SLM.**

I. Introduction

Based on the fundamental principle of recording with holograms, for the first time in 1965 Lohmann [1] produced the world's first computer-generated hologram. When producing a computer-generated hologram, a real object is not required, but only mathematical equations of the object wave are required. This process enables researchers to conveniently fabricate a holographic lens with its transmission function as a random two-dimensional joint function. This kind of holographic lens is adaptable to the spatial variation optical system in order to carry out optical transformations in meeting certain demands.

By using computer-generated holograms as the holographic lens, Bryngdahl [2,3] established a spatial variation optical system which can execute certain optical transformations, such as translation and partial contraction among others. Saito, et al [4] adopted the computer-generated holograms to conduct real-time optical ln(r) theta transformations, which can be applied to optical mode recognition. Casasent [5] executed the optical Mei-lin transformation with the computer-generated holograms.

Based on the foregoing, the work described in the paper describes how to use computer-generated holograms as a holographic lens in order to carry out the following optical transformations: ring-to-line, line-to-point and ring-to-point. (In the following text, ring-to-line, line-to-point and ring-to-point transformations are briefly expressed as ring-line, line-point and ring-point transformations). Two following methods can be used to generate computer-generated holograms: the first method is the conventional method; that is, a computer plotter serves to produce a computer-generated hologram before conducting the optical contraction. In the second method, a computer sends the encoded data of the computer-generated hologram to a liquid crystal television spatial light modulator, thus producing the computer-generated hologram in a quasi-real-time environment.

1. Optical transformation system

Fig. 1 is a spatial optical system for executing the optical transformations. It is assumed that an oscillation amplitude distribution object f(x, y) is placed at input plane I; the holographic lens H (that is, the computer-generated hologram) is placed just next to plane I. With illumination by parallel coherent light, when digit phase function phi(x, y) exists in H, the compound oscillation amplitude distribution F(u, v) of output plane O is

$$F(u, v) = \iint_{-\infty}^{+\infty} f(x, y) \exp[i\phi(x, y)] \exp[-ik(xu+yv)/f]\, dx\, dy, \qquad (1)$$

In the equation, k=2pi/lambda; lambda is the light wavelength. Let $h(x, y)=[\phi(x, y)/k]-[(xu+yv)/f]$; Eq. (1) is rewritten into

$$F(u, v)=\iint_{-\infty}^{+\infty} f(x, y)\exp[ikh(x, y)]dxdy. \quad (2)$$

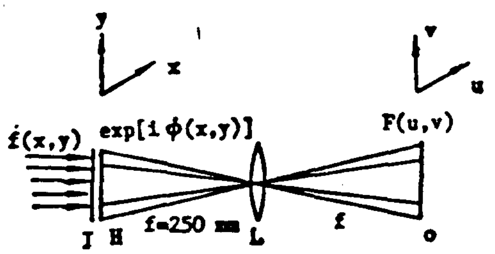


Fig. 1 Optical transformation system

For values greater than K, the value reached at the limit in the integration of Eq. (2) can be derived with the phase stabilization method [6]. It can be verified that a contribution to integral comes only from adjacent zones of some saddle points. At these saddle points, the following relationship obtains:

$$\frac{\partial h(x, y)}{\partial x}=\frac{\partial h(x, y)}{\partial y}=0. \quad (3)$$

From Eq. (3), we obtain

$$u=\frac{\lambda f}{2\pi}\frac{\partial \phi(x, y)}{\partial x}, \quad v=\frac{\lambda f}{2\pi}\frac{\partial \phi(x, y)}{\partial y}. \quad (4)$$

If we select a transformation from plane X-Y to U-V as

$$\begin{bmatrix} x \\ y \end{bmatrix} \rightarrow \begin{bmatrix} u=u(x, y) \\ v=v(x, y) \end{bmatrix}. \quad (5)$$

From Eqs. (5) and (4), we can solve for phi(X, Y) (if the equation can be solved). Then it is apparent that for some transformation from plane X-Y to plane U-V, the computer-generated hologram with phi(X, Y) displaced phase can be produced; the optical path in Fig. 1 can be used to produce the expected transformation.

2. Discussion on several types of transformation

As the following transformation:

$$\begin{bmatrix} x \\ y \end{bmatrix} \rightarrow \begin{bmatrix} u=x-y \\ v=y-x \end{bmatrix}, \quad (6)$$

This is a type of line-point transformation from plane X-Y to plane U-V; thus solving for the displaced phase function, we have

$$\phi(x, y) = \frac{\pi}{\lambda f}(x^2+y^2-2xy). \qquad (7)$$

For ring-line transformation, we can use

$$\begin{bmatrix} x \\ y \end{bmatrix} \to \begin{bmatrix} u = \ln(x^2+y^2)^{1/2} \\ v = \tan^{-1}(y/x) \end{bmatrix}, \qquad (8)$$

to derive the displaced phase function

$$\phi(x, y) = \frac{2\pi}{\lambda f}\left[-y\tan^{-1}\left(\frac{y}{x}\right)+x\ln\sqrt{x^2+y^2}-x\right]; \qquad (9)$$

The ring-point transformation can be accomplished if we merge the two above-mentioned transformations.

II. Experiments

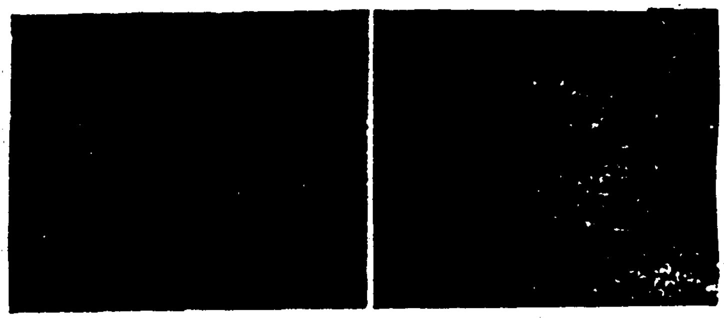
1. Generating computer-generated holograms

By using a He-Ne laser as the light source at light wavelength lambda=6328 nm; by taking the lens focal length as f=250mm. With a computer plotter, a Lee's model computer-generated hologram is produced. The dimensions of the computer-generated hologram are 20x20 cm^2. With optical reduction (50-fold reduction), a practical computer-generated hologram can be produced.

As used in the experiments reported in this paper, the liquid crystal television spatial light modulator was modified from a commercially available Citizens brand OBIA-OH black-and-white LCD television set; its screen dimensions are 71x53 mm^2, and the picture element points are 160x130 pixels. With appropriate modification of the electric circuits, additional video signals can be received. A computer sends the encoded data of the computer-generated hologram to the frame memory device, which converts the data into a video signal. The video signal is sent to a LCD television spatial light modulator to produce a computer-generated hologram in a quasi-real time environment as shown in Fig. 2.

2. Realization of optical transformation with computer-generated hologram

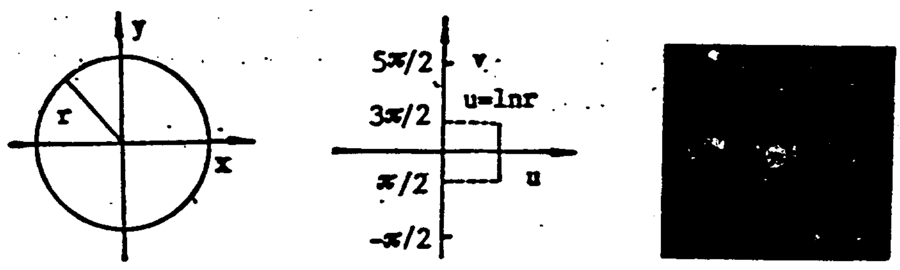
Using the optical path as shown in Fig. 1, on input plane I, the inputs are ring and line segments, respectively. The internal and external diameters of the ring are 2.5 and 3.0 mm respectively; the line width is 0.25 mm. After ring-line (or line-point) transformation, the theoretical and actual outputs on the output plane O are shown in Fig. 3(b) and (c), as well as Fig. 4(b) and (c). Combining the ring-line transformation and line-point transformation, the ring-point transformation can be executed. The experimental light path is shown as in Fig. 5; the inputs are shown in Fig. 3(a); and the actual outputs are shown in Fig. 6.



(a) (b)

Fig. 2 CGH generated by LCTU. SLM

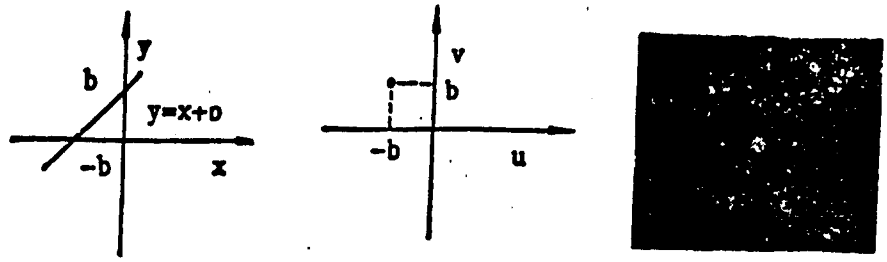
(a) For ring-to-line (b) For line-to-point



(a) (b) (c)

Fig. 3 Ring-to-line transformation

(a) I plane input distribution; (b) O plane theoretical output distribution; (c) O plane practical output distribution, center: 0-order diffraction, both sides: ±1-order diffraction.



(a) (b) (c)

Fig. 4 Line-to-point transformation.

(a) I plane input distribution; (b) O plane theoretical output distribution; (c) O plane practical output distribution, center: 0-order diffraction, both sides: ±1-order diffraction

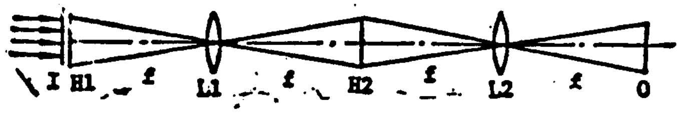


Fig. 5 Ring-to-point transformation diagram
Focus of L1 and L2: f=250mm, H1 and H2: OGH for ring-to-line and line-to-point transformations respectively, I and O; input and output planes.

Fig. 6 O plane practical output distribution in ring-to-point transformation

III. Conclusions

Experiments in the paper verify the fact that optical transformation can be accomplished with computer-generated hologram. As the computer-generated hologram has quite good flexibility, such hologram is quite adaptable to use as an element for optical transformation to accomplish optical transformation in meeting various requirements.

Time required for producing computer-generated hologram is an important problem. In the paper, liquid crystal television spatial light modulator is used to produce the computer-generated hologram at quasi-real time environment. This method is still rare in China as not requiring the time-consuming processes of computer drafting of diagram and optical reduction. There are the following advantages for this method: time economizing, easy to store and modification, and not requiring such labor-intensive processes as computer drafting and optical reduction. This is a very practical experiment method. In the paper, the resolutions produced by the liquid crystal television spatial light modulator are relatively low. In the authors' view, it is not difficult to

produce a 1024x1024 or even higher spatial bandwidth with similar methods.

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